Lineament mapping using sig and optical and radar remote sensing: the case of the Tafilalet plain (Southeastern Morocco)

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Abstract. This research focuses on the mapping of lineaments in the Tafilalet plain, located in south-eastern Morocco, using a combination of optical (Landsat 8), radar (Sentinel-1A) and 10 m resolution digital terrain model (SRTM) remote sensing. Radiometric and geometric corrections, as well as directional filters, were applied to extract lineaments of the study area. These lineaments were then validated using geological and topographical maps and Google Earth Pro images. Statistical analysis of the orientations revealed six main directions: N-S, NE-SW, NW-SE, E-W, NNE-SSW, NNW-SSE, with a predominance of N-S to NE-SW orientations, corresponding to the hydrological dynamics of the region. This approach demonstrates the effectiveness of remote sensing techniques in providing precise information on geological structures, thereby facilitating understanding of the subsurface and hydrological characteristics of the area studied.

Keywords. Lineaments, GIS, Optical/Radar remote sensing, SRTM, Tafilalet plain.

1 Introduction

Water is a vital element for humanity due to its impact on social, economic, and ecological aspects. In southern Morocco, the lack of water represents a major obstacle to sustainable development and population stability. In particular, groundwater exploitation has become essential, especially in agriculture, where 65% of the water used for irrigation comes from groundwater sources [8, 11].
The study area of this research is the Tafilalet plain, located in southeastern Morocco, known for its oases and palm groves.

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This desert region, bordered by the High Atlas and Anti-Atlas mountain ranges, has historically played a significant role as a commercial crossroads in the Saharan trade network. Geological lineaments, which indicate faults and deep structures, are of great importance in hydrogeology. Their presence often reveals water potential, crucial for water resource management.
The objective of this work is to map these lineaments, a task facilitated by optical and radar remote sensing, which provides an overview of surface structures [6]. It also provides access to remote or inaccessible regions [6]. However, factors such as vegetation, recent deposits, land use or sensor resolution can hamper the identification of lineaments by remote sensing.

2 Study area

The Tafilalet plain, located in southeastern Morocco, is an arid depression covering 700 km², crossed by the Ziz and Rhéris rivers [1, 10]. Geologically, it lies between the Anti-Atlas mountain range and the high plateaus, with sedimentary rocks ranging from the Paleozoic to the Quaternary periods [10]. Its semi-desert climate is characterized by very low annual precipitation and temperatures that can reach up to 50°C in the summer [3, 4]. Hydrologically, the Ziz and Rhéris rivers drain the plain, while hydrogeologically, it contains a Paleozoic aquifer and a Quaternary water table that are essential for irrigation, with an average transmissivity of 1 to 2.10^{-3} m³/s [2, 5, 9]. Precipitation patterns show a general trend towards dryness [7].

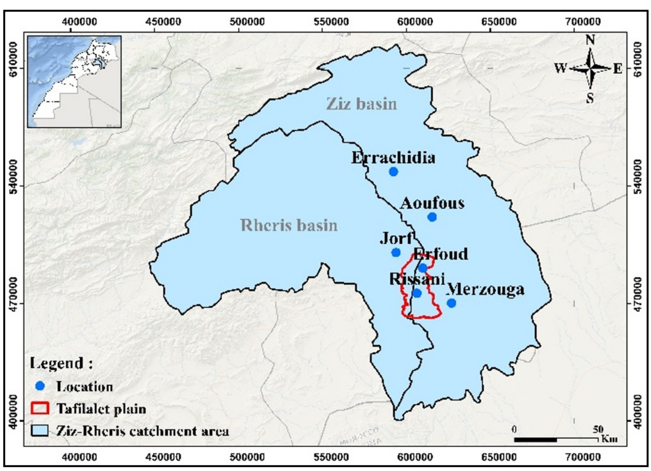

Fig. 1. Geographical location of the Tafilalet plain within the Moroccan basins.

3 Materials and methods

3.1 Dataset

The data analyzed in this work include a Digital Elevation Model (SRTM) and satellite images from Landsat-8 OLI and Sentinel-1A. The Landsat-8 OLI image, dated April 3, 2024, and the Sentinel-1A radar image, both with a spatial resolution of 10 m, were processed using the SNAP and ENVI software, respectively. Additional analyses and processing were conducted using ArcGIS. The SRTM, also at a spatial resolution of 10 m, was extracted from the Sentinel-1A radar image.

3.2 Methodology

This work is based on the collection of data from three main sources: the Landsat-8 OLI image, the Sentinel-1A image, and the Digital Elevation Model (SRTM) with a resolution of 10 m, each subjected to specific preprocessing steps.
- For the Landsat-8 OLI image, preprocessing includes radiometric and geometric corrections, followed by Principal Component Analysis (PCA) to select informative bands. A directional filtering (0°, 45°, 90°, and 135°) is applied to the chosen band (PC1) to enhance the lineaments.

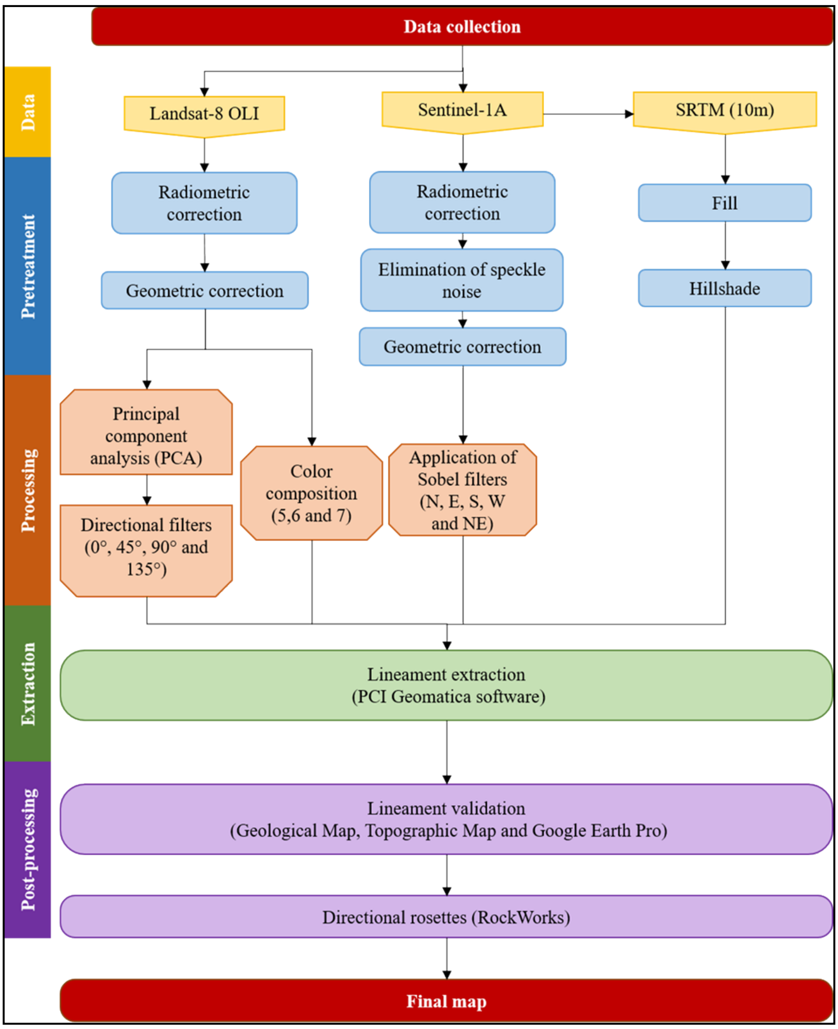

Fig. 1. Workflow diagram of the overall methodology adopted for lineament extraction.

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- The Sentinel-1A images undergo radiometric corrections and speckle noise removal. The Sobel filter (North, East, South, West, and Northeast) is then used to extract the lineaments.
- For the Digital Elevation Model (SRTM), preprocessing includes filling (fill) to correct any anomalies and applying the hillshade tool to generate shadows that emphasize the terrain.
- Lineaments are extracted using PCI Geomatica, validated against geological and topographic maps as well as Google Earth Pro images, and statistically analyzed using directional rose diagrams with Rockworks software.

4 Results and discussion

The map of lineaments extracted from the Landsat 8 OLI image (Fig. 3) according to different directions (0°, 45°, 90°, 135°) reveals a diversity in the orientation of geological structures, reflecting the tectonic complexity of the region. Each direction highlights distinct elements of the fault and fracture network. The north-south orientation (0°) appears to correspond to major regional faults, while the 45° inclination suggests shear zones and oblique fractures. The east-west direction (90°) is indicative of transform faults, whereas the southeast-northwest direction (135°) shows secondary structures related to more complex tectonic stresses. These variations in the orientation of lineaments emphasize the multiple influences of tectonic forces on the region's morphology, with implications for underground dynamics, particularly regarding the flow and infiltration of groundwater.

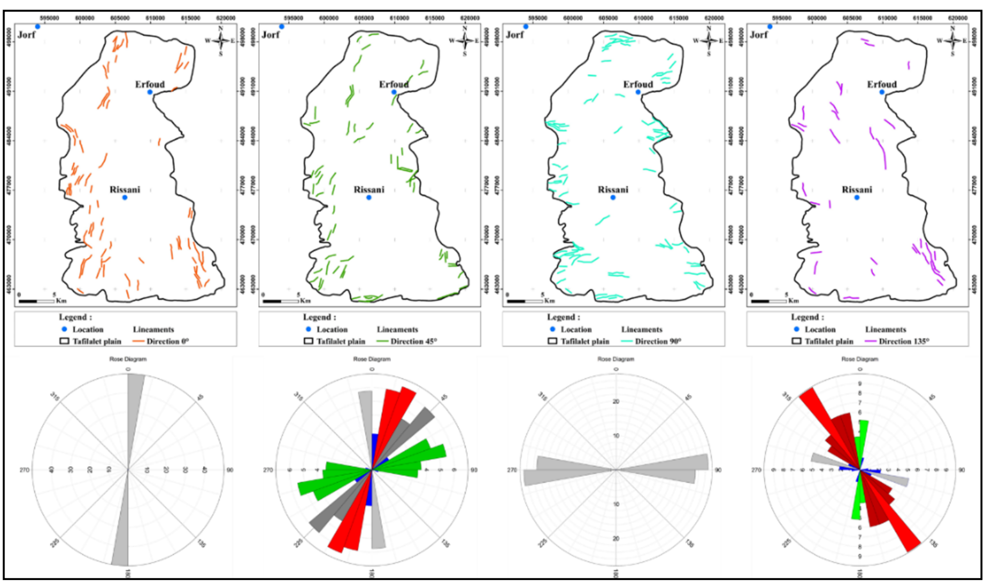

Fig. 2. Lineaments extracted from the Landsat 8 OLI image using different directional filters and their directional roses.

The map of lineaments developed from the false-color composition of bands 5, 6, and 7 of Landsat 8 (Fig. 4) highlights significant spectral variations **(a)**, facilitating the identification of geological lineaments. This band combination enhances the contrast of surface structures, allowing for the distinction of areas with specific soil types or vegetation cover that influence hydrological dynamics, particularly aquifer recharge. Additionally, the lineament map derived from the Digital Elevation Model (SRTM) **(b)** complements this analysis by revealing topographic structures associated with major fractures-oriented northwest/southeast and east/west, reflecting the main geological faults of the region. The combined use of spectral and topographic data provides a more integrated view of the local geological and hydrological characteristics.

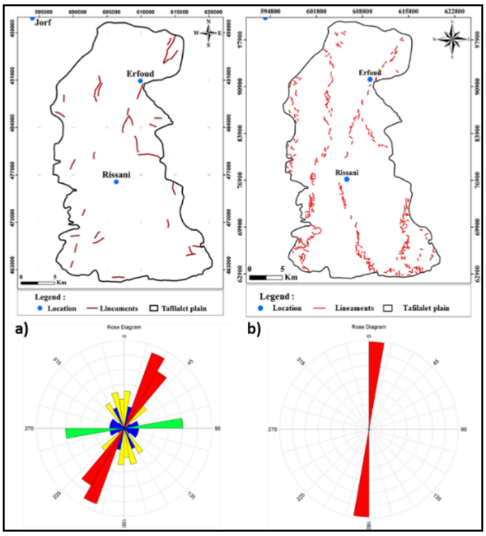

Fig. 3. a) Lineament map of colored composition 5-6-7; b) DTM lineament map (SRTM), and its directional roses.

The lineaments extracted from the VH band of the Sentinel-1A image (Fig. 5) using the Sobel filter reveal various orientations depending on the angle of the applied filter. The east-oriented filter highlights lineaments primarily in the east-west and north-south directions, emphasizing fractures and faults that may influence groundwater flow and aquifer recharge. When applying the north-oriented filter, the identified north-south and east-west lineaments indicate regional compression and strike-slip faults, creating preferential pathways for water and increasing the availability of groundwater resources. Finally, the northeast-oriented filter reveals northeast/southwest and northwest/southeast structures, suggesting oblique faults and complex fractures that facilitate surface water infiltration and enhance groundwater recharge.

The lineaments extracted from the VV band of the Sentinel-1A image (Fig. 6) using Sobel filters reveal various orientations depending on the angle of the applied filter. The east-oriented filter highlights structures primarily in the east-west and north-south directions, providing fine details about geological structures that are often invisible in VH polarization and indicating potential conduits for water flow and groundwater recharge. The north-oriented filter reveals north-south and east-west faults, corresponding to regional compression and strike-slip faults that also facilitate aquifer recharge. Finally, the northeast-oriented filter shows northeast/southwest and northwest/southeast lineaments, illuminating fracture zones and oblique faults, with northeast/southwest faults promoting water infiltration and northwest/southeast lineaments indicating areas of high permeability.

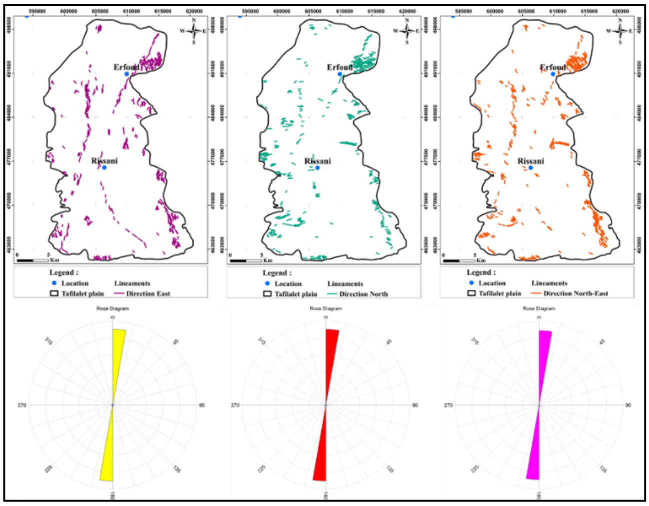

Fig. 4. Lineaments extracted from the Sobel filter of the VH polarisation of the Sentinel-1A image with different directions, and their directional roses.

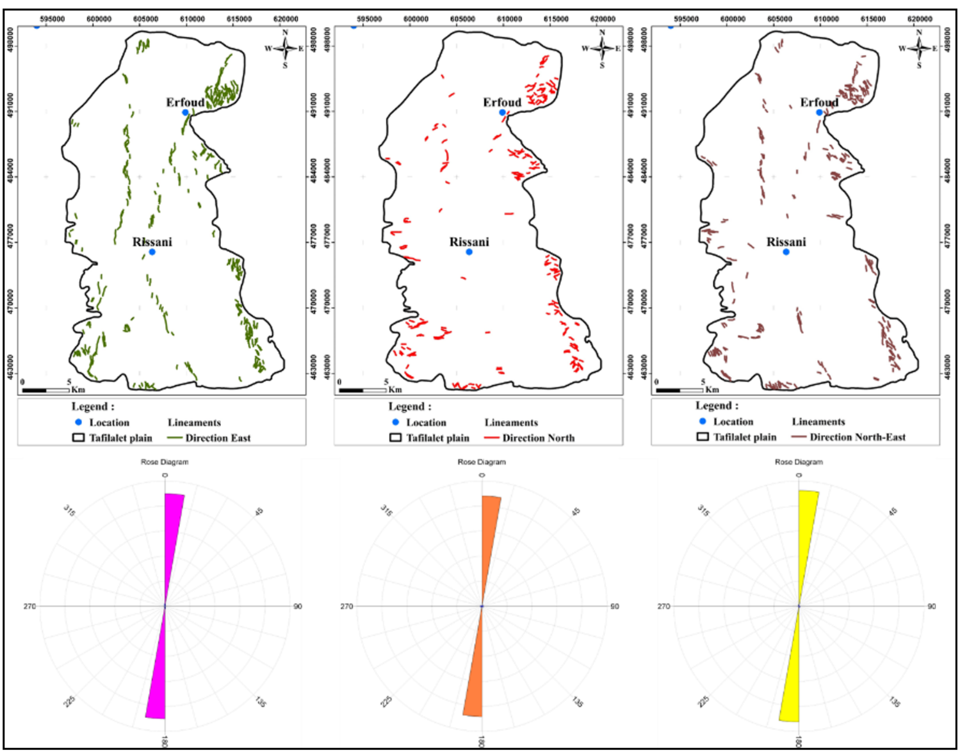

Fig. 5. Lineaments extracted from the Sobel filter of the VV polarisation of the Sentinel-1A image with different directions, and their directional roses.

The combined map of lineaments extracted from Sentinel-1A (VH and VV polarization in multiple directions) and Landsat-8 OLI (Fig. 7) shows orientations of east-west, north-south, northwest/southeast, and northeast/southwest. The integration of optical and radar data allows for capturing a comprehensive range of geological structures, validating the identified lineaments and enhancing the accuracy of fault and fracture mapping. This combination provides a thorough understanding of the structures influencing groundwater circulation. The detected lineaments indicate recharge areas for aquifers and preferential pathways for water flow, which are crucial for water resource management in the Tafilalet plain. This information aids in identifying areas suitable for groundwater extraction and in planning drilling activities.

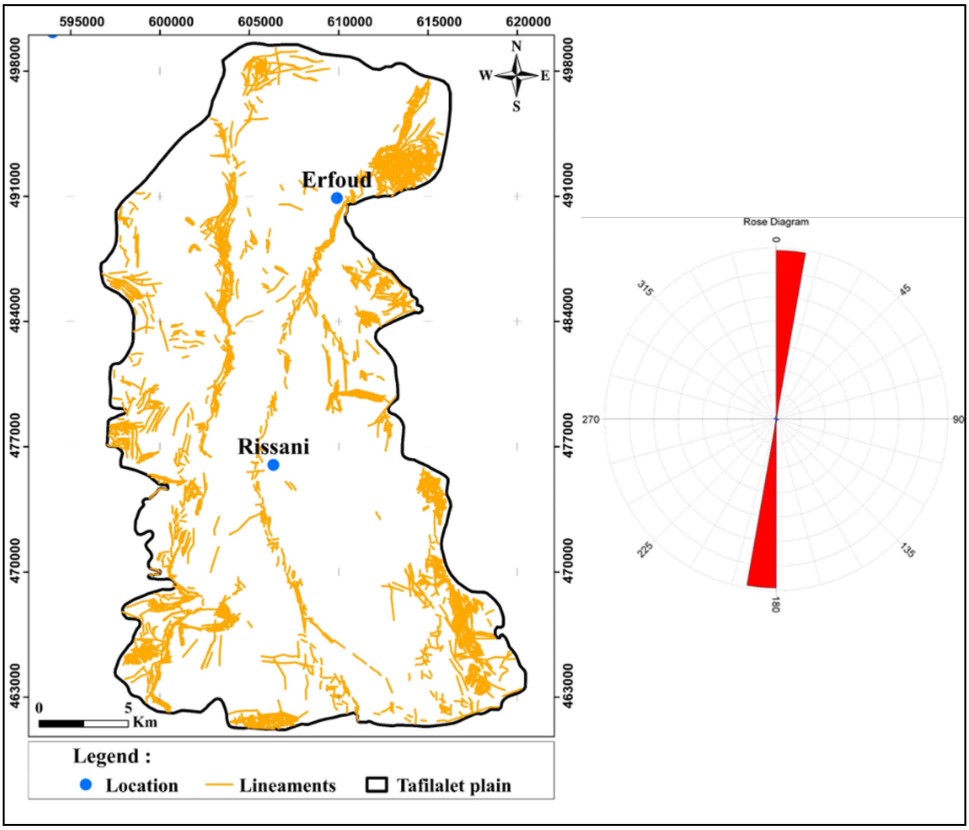

Fig. 6. Final map of all lineaments extracted from Landsat 8 Oli, SRTM and Sentine-1A satellite images.

5 Conclusion

Optical and radar remote sensing provides a comprehensive and detailed view of large geographical areas, essential for mapping lineament structures and understanding regional tectonics. This work focuses on the Tafilalet plain in southeastern Morocco, a desert region bordered by the High Atlas and Anti-Atlas mountain ranges, known for its oases and commercial history. By utilizing satellite images from Landsat-8 OLI, Sentinel-1A, and a Digital Elevation Model (SRTM) with 10 m resolution, this research has successfully identified and analyzed lineaments in the area, revealing six main orientations (N-S, NE-SW, NW-SE, E-W, NNE-SSW, NNW-SSE), with a predominance of the N-S and NE-SW directions. The results indicate that the lineaments align with the hydrological patterns of the region. Radar remote sensing is considered complementary to optical remote sensing in this analysis.

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Author contribution
Ouafae Mouzoun and Chaimae Iharzi contributed to the study design, data processing, and drafting the manuscript. They assisted with data interpretation, statistical analyses, and proofreading. Amina Kassou and Ali Essahlaoui supervised the project, provided guidance, and critically reviewed the final manuscript. Abdelali Khrabcha provided important suggestions.
Ethics approval and consent to participate
Not applicable.
Consent for publication
All the authors have agreed to publish this article.
Competing interests
The authors declare that they have no competing interests.
Data availability statement
The data used in this study are freely available and accessible through the USGS Earth Explorer platform.
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